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Prioritizing electric miles over electric vehicles will deliver greater benefits at lower cost

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Supplementary material for this article is available [online](#)

Introduction

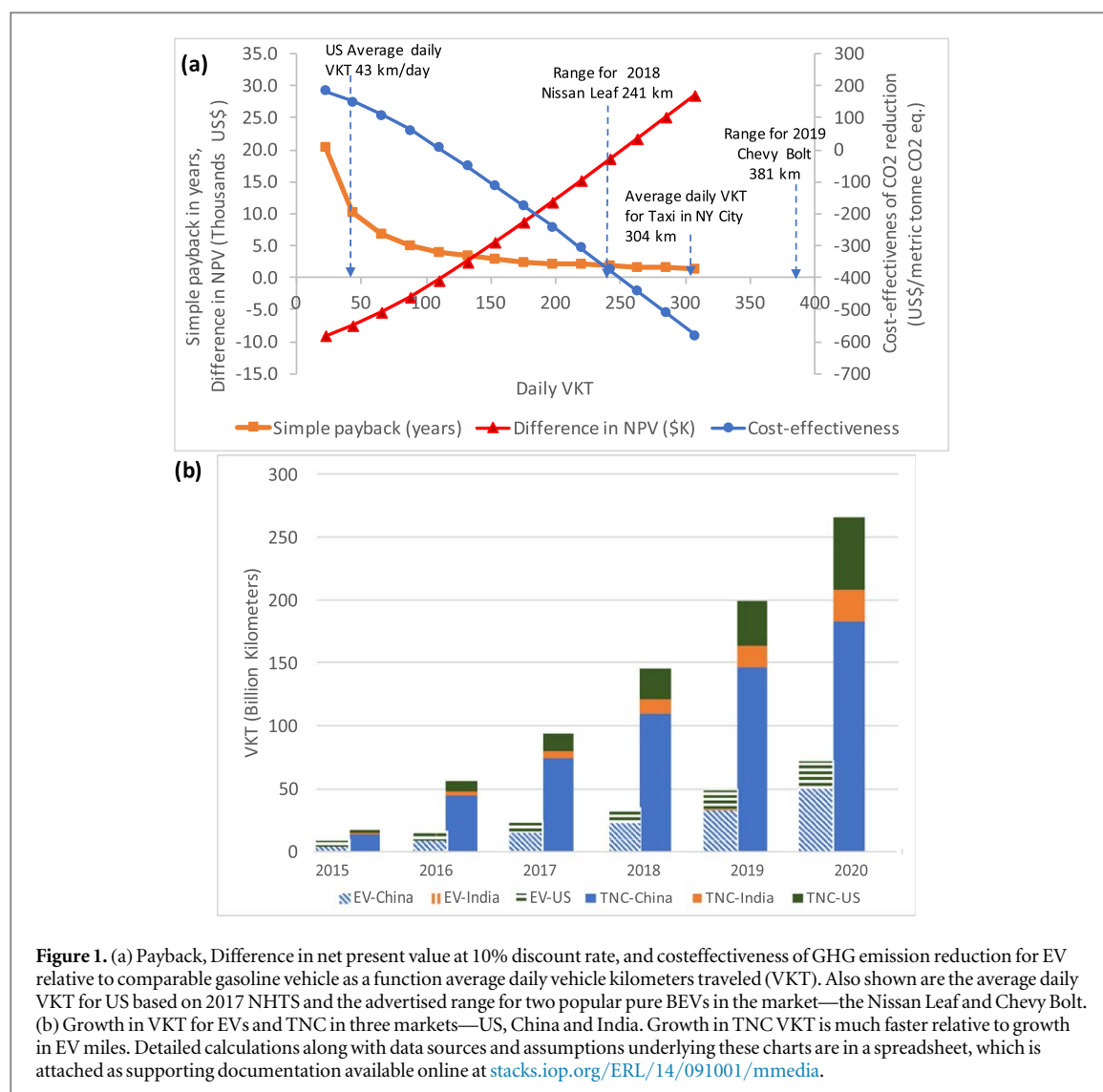
Compared with gasoline- and diesel-powered vehicles, pure battery electric vehicles (simply, BEVs) are much more energy efficient, make essentially zero contribution to urban air pollution, and hold enormous potential for climate change mitigation [1, 2]. The climate benefits indeed depend on the greenhouse gas intensity of the electricity source, but we take it as a given that decarbonizing electricity is also a policy priority for jurisdictions serious about EVs. Diffusion of BEVs is therefore key to reducing global crude oil consumption, decarbonizing transportation, and improving urban air quality [3–5].

BEV adoption is supported through various types of incentives for vehicle purchase, including income tax credits (e.g. US), vehicle subsidies (e.g. France, China), exemptions from value-added taxes (e.g. Sweden), rebates on annual ownership fees (e.g. Norway), and waivers from CO₂ (e.g. UK) [6, 7]. Some jurisdictions, including California and China, are implementing policies that require vehicle manufacturers to produce a certain share of zero-emission vehicles or buy credits from others to meet the requirement. Finally, BEVs benefit from free public charging, parking, access to toll roads and high-occupancy-vehicle lanes [6, 7].

While the current policies have increased EV adoption, they do not fully exploit the potential of EVs. One reason is that in spite of incentives amounting to about 25% of the vehicle cost, BEVs still seem costly not only upfront but also on a lifecycle cost (LCC) basis, a plausible explanation for their slow adoption [4, 8, 9]. For example, the \$7500 US federal tax credit alone amounts to a 20%–25% discount on the retail price of popular EVs in the US market today. Even with this level of incentives, at the US average

daily vehicle kilometer traveled (VKT), which is 43 km per day [10, 11], the payback to EVs relative to a comparable pure gasoline vehicle is about a decade long. Furthermore, when discounting future savings at 10%, the LCC savings are, in fact, negative (figure 1(a)). For BEVs to even just breakeven on a LCC basis requires twice the average daily VKT, which is the 90th percentile of the VKT distribution [11], and this level of use would still entail a five-year long payback. Of course, these estimates are sensitive to electricity and gasoline prices but it is clear the economics are still unfavorable for most private households [12]. This implies current adopters differ in their characteristics when compared to rest of the society. Even though battery cost is expected to decline [12], the larger battery packs required to meet longer driving range expectations could temper the decrease in upfront cost of BEVs. Lastly, without a carbon price, any reduction in gasoline and diesel demand due to a global transition away from fossil fuels would reduce gasoline and diesel prices, increasing the payback period [7]. This implies a sustained—and potentially even greater—reliance on public subsidies. Recent developments lend some support to this claim. Under current US federal policy, the full \$7500 subsidy is available only to the first 200 000 vehicles sold by each automaker. However, efforts are underway to extend the per automaker cap for the full federal subsidy while another effort aims to increase the state subsidy California from \$2500 to \$4500 per EV [19].

Second, under current policies, BEVs compete with plug-in hybrid EVs (PHEVs), which offer only a fraction of the electric driving range relative to BEVs. PHEVs account for about 50% of all passenger EVs in the United States, and 47 of the 77 distinct models eligible for federal tax credits are PHEVs, which is an



implicit subsidy for gasoline or diesel use. (see www.fueleconomy.gov/feg/taxevb.shtml)

Third, BEV ownership is disproportionately concentrated among high-income households and communities. Data from California's Clean Vehicle Rebate Project suggest that only 6% of the California rebates for BEVs were captured by households in disadvantaged communities [13]. Therefore, under current policies, the benefits to low-income households of BEV policies accrue mainly indirectly through reduced pollution due to BEV adoption by wealthier households. Specifically, in the case of income tax credits, poor households might also not have the level of tax liability to take full advantage of the tax credits. Viewed through an equity and environmental justice lens, policies must change if low-income households are to benefit directly from public support for BEVs.

Indeed, there are other barriers impeding EV adoption including lack of a widespread fast-charging infrastructure, which is the reason for the so-termed range anxiety, credit constraints, limited choice set of vehicle models, and well-known behavioral failures that inhibit adoption of efficient technologies with

lower LCC. We relate to some of these issues when we discuss the merits of the policy innovation we outline below.

To address these issues and for the simple reason that payback is inversely correlated with VKT, we suggest pivoting public policies to target high-usage vehicles and applications. As an illustrative example, in the US, EV payback falls from 10 years to two years when VKT increases five-fold from the national average of 43–215 km d⁻¹ (figure 1(a)). But high-VKT users who could benefit from the lower LCC of EVs even in the absence of subsidies would still face barriers in the form of range anxiety, while some might additionally also face credit constraints. However, the stock of private vehicles with such high levels of VKT is small (about 0.2% of the population in the US) [13] and diffuse, which in fact weakens the economic case for public investment in expensive fast-charging infrastructure.

It is in this context that the explosive worldwide growth of ride services provided by transportation networking companies (TNC) such as Didi, Lyft and Uber presents a new opportunity to re-pivot BEV policies. In 2017, the total VKT of all TNC vehicles in

China, India, and the United States was four times the VKT of all EVs combined in these countries (figure 1(b)). Although reliable data on average VKT per TNC vehicle are lacking, the average VKT for conventional taxi cabs in New York City is 304 km d⁻¹ [14], which translates into a simple payback period of about 1.5 years and a LCC savings of about \$28 000 (at a 10% discount rate) in lifecycle ownership cost savings after taking into account battery replacement costs and the US federal subsidy (figure 1(a)). High-VKT applications also afford greater cushion for BEVs to absorb the cost of bigger battery packs and remain competitive despite future increase in fuel economy of ICE vehicles or a decline in oil price or both.

Although BEVs may deliver significantly greater lifecycle benefits under such (high usage) conditions, they entail some unique adoption challenges. A two-year or quicker payback notwithstanding, the higher upfront cost of BEVs is plausibly still a barrier for TNC and taxi drivers who tend to belong to lower-income households and face credit constraints. Furthermore, a two-year payback greatly exceeds the expected duration of employment for the vast majority of TNC drivers but not for taxi drivers [15]. Secondly, high-mileage users also require convenient access to fast-charging infrastructure. The policy approach we

consumer loans for capital investments have each by themselves been tried in the electric power sector although the two have not been coupled as suggested here. For instance, a subsidy per kilowatt of hour electricity produced, known as a production tax credit (PTC) in the US, has been shown to accelerate diffusion of wind energy [16]. A loan for financing purchase of roof top solar panels, known as property assessed clean energy, has been shown to positively impact residential solar PV diffusion in the US [17, 18].

EVs appear a suitable application for use-based subsidies because low-cost reporting and verification seems plausible. For instance, TNCs already charge consumers on a per-mile basis. The California Clean Miles Standard [20] that requires a certain share of annual total miles serviced by TNCs to be electric is predicated on reporting of this information. For private VKT, there needs to emerge a simple protocol for reporting this information, which is already available to EV owners or is tracked and recorded but not displayed to PHEV owners. This could be accomplished through a smart phone application or directly relayed by on-board communication systems to a central server belonging to a regulatory agency.

Subsidy per eVKT relates to usage and payback as follows.

$$\text{Payback} = \frac{|\Delta \text{Vehicle cost}|}{(|\Delta \text{operating cost per km}| + \text{subsidy per km}) * \text{eVKT}_{\text{annual}}}$$

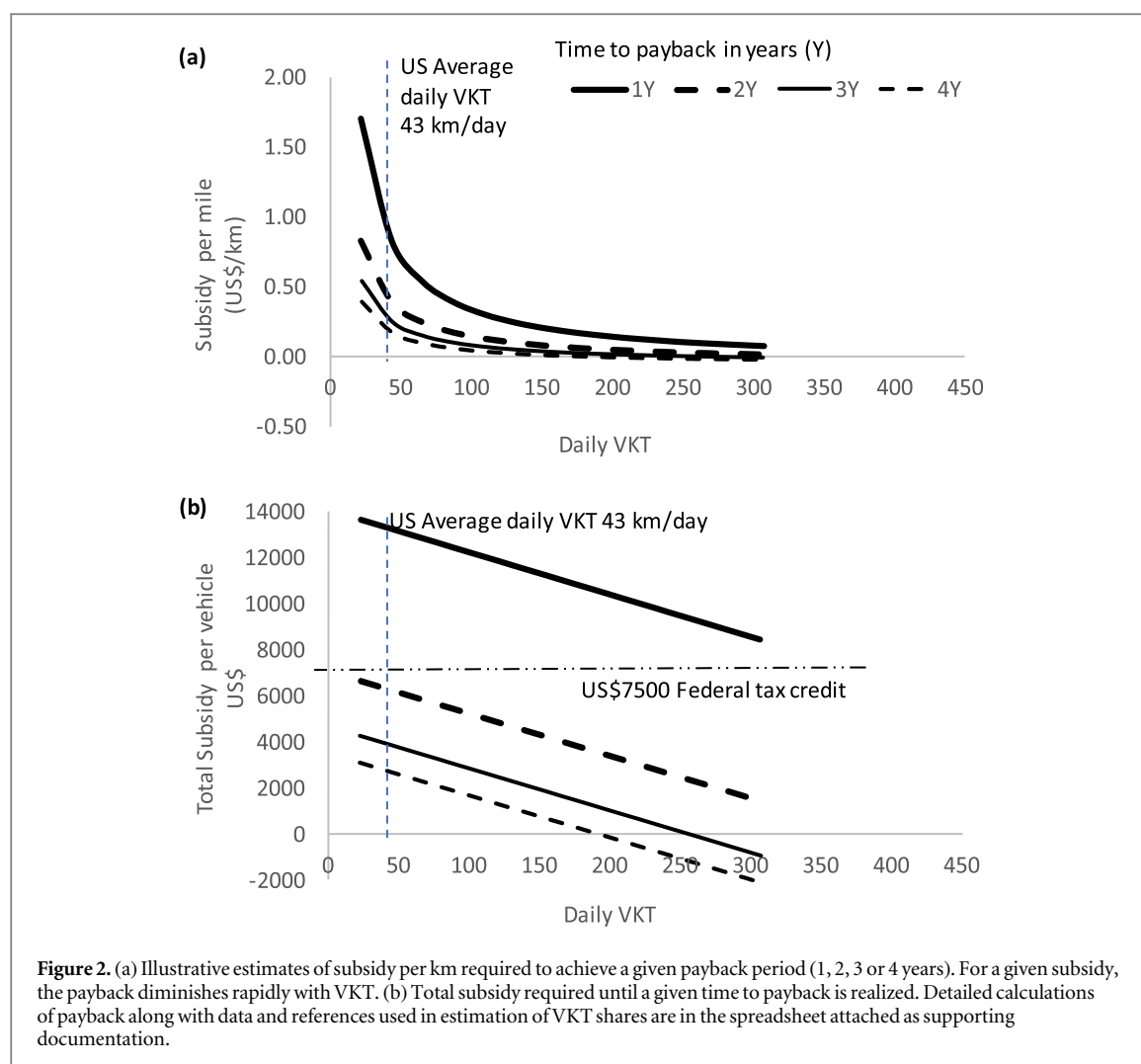
outline below to address these issues. In doing so we emphasize TNC and taxis, but the policies apply also to private-use vehicles as well as commercial light duty vehicles while the basic insight extends to heavy duty vehicles as well.

The direct approach to target high-mileage users is to provide a subsidy per-electric VKT (eVKT) along with an option to finance the incremental cost of EV purchase through a government loan, that is recouped in lieu of the subsidy. The per-eVKT subsidy is also a simple way to avoid implicitly subsidizing gasoline or diesel miles as is the case with PHEV owners who benefit from lump-sum EV subsidies today. Use-based subsidies are a targeted way to internalizing positive externalities that arise from learning-by-seeing and learning-by-experiencing. High-mileage users of EVs also provide greater external benefits by creating more familiarity with the technology by simply being on the road more. In the case of taxis and ride-sourcing vehicles, they also help potential adopters experience riding, and also gain actual user insights by potentially conversing with the driver.

Although economists have known use-based subsidies to be efficient, actual experience has been minimal plausibly due to the lack of a low-cost reporting and verification mechanism. Use-based subsidies and

For a given annual eVKT, targeting a quicker payback implies a higher subsidy and viceversa. For a given payback, greater the annual eVKT target smaller the minimum subsidy required. Figure 2 numerically illustrates these relationship for a Chevy Bolt BEV relative to an equivalent gasoline vehicle. An average eVKT of 100 km d⁻¹ requires a subsidy of \$0.13 per km and total subsidy of \$5000 for a two-year payback, which is 33% cheaper than the current US federal subsidy per EV and delivers more than twice the reduction in gasoline use and GHG emissions assuming the average EV displaces the average gasoline vehicle. An average eVKT of 200 km d⁻¹ requires a subsidy of \$0.05 per km and total subsidy of \$3400 for a two-year payback.

A general concern with use-based subsidies for vehicles is that on the margin it provides incentives to drive more, which is referred to as rebound effect. First, this is a second-order effect. Second, the calculations reveal that such behavior is highly unlikely as the marginal cost of fuel, maintenance, and depreciation likely exceeds the subsidy per km even if one ignores the opportunity cost of time spent driving. Third, one could also cap the total subsidy per vehicle which eliminates an incentive. It is also worth noting that for EVs that are powered with clean electricity, rebound is not



associated with pollution externalities but only congestion externalities potentially. But arguably only a fraction of the increase TNC and taxi trips adds vehicles because some trips displace private vehicle use and some trips are shared. That said, the direct approach to addressing congestion is to price congestion, or creating targeting incentives for shared-modes and carpooling that are independent of vehicle propulsion technology.

In spite of the advantages of use-based subsidies, lump-sum subsidies have certain advantages. For instance, learning-by-doing and scale economies on the production side are independent of the intensity of product use. In such situations, one option is to use lump-sum subsidies at the early stages after which lump-sum subsidy is gradually replaced with a use-based subsidy. A second option is to offer both simultaneously but mutually exclusively, where adopters self-select into one of the two schemes. With each of these formulations, policy makers could adjust the level of each type of subsidy and their timing to depending on budgetary constraints and the rate of diffusion.

Although the focus here is on making the case for use-based subsidies, we wish to make it clear that it is but one instrument within a broader policy ecosystem

aimed at EV adoption in high-usage applications. Subsidy reform needs to be complemented with efforts to create a wide and dense fast-charging infrastructure aimed at TNC and taxi vehicles while also ensuring that facilities that are publically-funded are accessible to private-use vehicles. Finally, given that mandates are already being adopted, one can expect this would induce TNCs to facilitate EV adoption through a combination of innovative vehicle leasing programs and incentives, and investments in creation of fast-charging network and driver education and awareness programs. To the extent, use-based subsidies are captured by TNC drivers, it reduces the incidence of the burden on the TNC industry.

To summarize, there is a strong case for redesigning EV incentives given sustained high subsidy requirements, absence of pollution pricing, and most importantly, the rise of ride-sourcing. Vehicle subsidies appear simpler at the very early stages of diffusion, but the timing is now right for a shift towards policies that directly targets BEV use. Use-based incentives together with financial assistance for EV purchase and creation of a fast-charging infrastructure, would exploit the proliferation of high-use vehicles associated with on-demand transportation

services while also continuing to support EV adoption for private household use. Such a shift has the potential to deliver greater environmental benefits faster, directly benefit poor households, and can be implemented at low administrative cost.

Data availability statement

Any data that support the findings of this study are included within the article in the supporting information document available online.

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